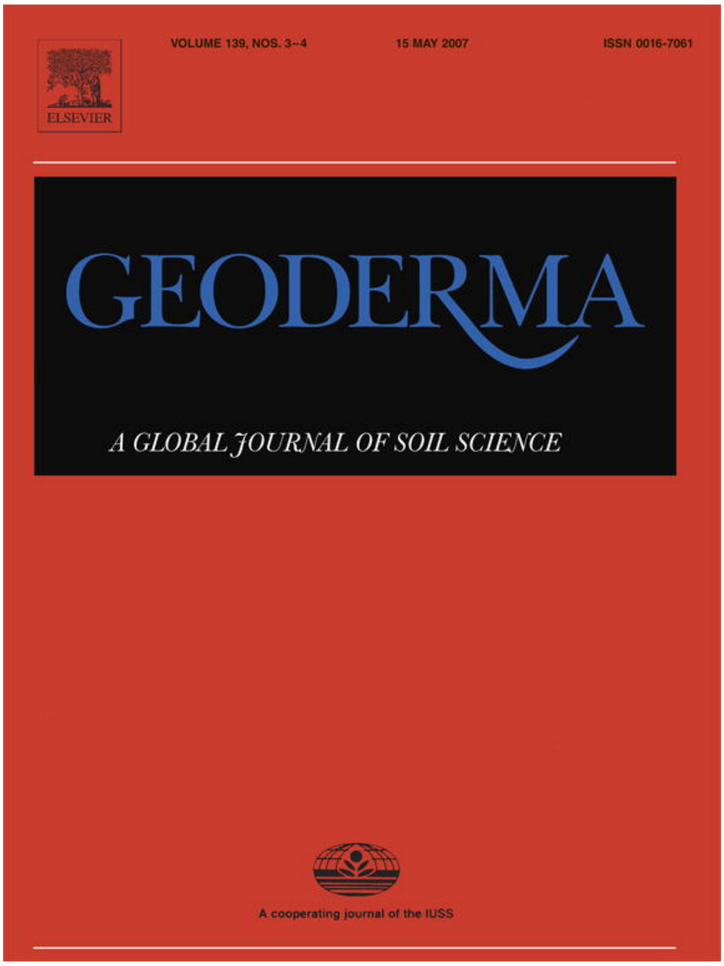

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Determination of the wind-erodible fraction of soils using different methodologies

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Abstract

The wind-erodible fraction of the soil (EF) (percentage of aggregates <0.84 mm in diameter) is a key parameter to estimate the soil susceptibility to wind erosion. The standard method for EF determination is the dry sieving by means of a rotary sieve. Flat sieving with a set of sieves and the use of the equation EF=(29.09+0.31 sand+0.17 silt+0.33 sand/clay-2.59 organic matter-0.95 $CaCO_3$)/100, R^2=0.67, [Fryrear, D.W., Krammes, C.A., Williamson, D.L., Zobeck, T.M., 1994. Computing the wind erodible fraction of soils. J. Soil Water Conserv. 49: 183–188] are two alternative ways of determining EF. As the flat sieving has still not been contrasted against the standard rotary sieve method nor the Fryrear et al. equation tested for soils other than US soils, we estimated EF with both dry sieving methods and tested the equation for soils of semiarid regions of Central Aragon (NE Spain) and the Semiarid Pampas (centre of Argentina), two regions prone to wind erosion. Results showed that EF values obtained with the flat sieve were comparable with those obtained using the standard rotary sieve, indicating that the flat sieving technique is suitable for EF determinations. The estimation of EF with the model proposed by Fryrear et al. [Fryrear, D.W., Krammes, C.A., Williamson, D.L., Zobeck, T.M., 1994. Computing the wind erodible fraction of soils. J. Soil Water Conserv. 49: 183–188] did not fit with the measured EF values, indicating that this model is not useful for predicting EF in Spanish and Argentinian soils. This was attributed to the high $CaCO_3$ contents of Spanish soils and the low sand/clay ratios and high organic matter contents of some Argentinean soils. The equation EF=9.98+6.91 sand/clay+14.1/organic matter (r=0.933; P<0.001) was proposed to predict EF in the studied soils.

Keywords: Wind-erodible fraction; Dry sieving; Rotary sieve; Flat sieve; Model validation

1. Introduction

Wind erosion is an important soil degradation process in arid and semiarid regions. It produces not only negative effects on soil properties (Buschiazzo and Taylor, 1993; Zobeck and Fryrear, 1986) but also a deterioration of the environment, including human health (Wilson and Sprengler, 1996). Due to these negative consequences, the comparative prediction of wind erosion in soils submitted to different management conditions is necessary to avoid irreversible degradation processes of the ecosystem.

The relationships between soil losses by wind erosion and soil surface properties (cloddiness, vegetative cover, roughness) were first established from wind tunnel tests as early as 1950s (Chepil and Woodruff, 1954). Based on soil sieving and wind tunnel experiments, Chepil (1950) observed that aggregates larger than 0.84 mm in diameter were non-erodible in the range of wind speed used in the tests. Since then, the wind-erodible fraction of soils, EF, (aggregates<0.84 mm in diameter) has been a key parameter to estimate the soil susceptibility to wind erosion and, thus, has been considered in the prediction models, as the current Revised Wind Erosion Equation, RWEQ (Fryrear et al., 1998, 2000).

The standard method for EF determination is the dry sieving by means of the rotary sieve (Chepil, 1962). This device simulates the destruction of soil aggregates by abrasion due to the

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impact of particles transported by wind. The rotary sieve is not commercially available and several authors have developed alternative methods to determine EF. The flat sieve is an alternative dry sieving device more readily available in the laboratories of soil physics. Toogood (1978) adjusted a dry sieving method based on the flat sieving of soil aggregates in a set of sieves. Buschiazzo et al. (1994) modified the Toogood's dry sieving method adapting it for soils of the semiarid Argentina. López et al. (2001) quantified the susceptibility of soils of semiarid Aragon (Spain) to be eroded by wind determining EF with a flat sieve.

Fryrear et al. (1994) proposed a multiple regression equation for calculating EF in those cases where a rotary sieve is not available. This equation considers the contents of organic matter, sand, silt, clay and calcium carbonate as predictive variables. Fryrear et al. (1994) indicated that this equation has restrictions and that must be tested for soils different from US soils, for which this equation was developed.

EF results obtained with flat sieving methods have still not been compared with EF obtained with the standard rotary sieve method. On the other hand, the usefulness of the equation proposed by Fryrear et al. (1994) has been not tested yet for soils other than US soils. Because of that the objectives of this study were to analyze the efficacy of dry sieving with a flat sieve machine to measure EF and to test the equation proposed by Fryrear et al. (1994) to predict EF for soils of semiarid regions of Central Aragon (NE Spain) and the Semiarid Pampas (centre of Argentina), two regions prone to wind erosion.

2. Materials and methods

A total of 22 farmer fields were selected in the Semiarid Pampas (centre of Argentina) and 5 farmer fields were selected in Central Aragon (NE Spain). The fields from Argentina were located between latitudes 35° 40′S and 37° 18′S and longitudes 63° 59′W and 64° 20′W. The elevation of the fields ranged from 190 to 220 m a.s.l. and all sampled fields were level. The fields sampled in Spain were located between 41° 31′N and 41° 43′N latitude and 0° 46′W and 1° 8′W longitude. The elevation varied from 260 to 610 m a.s.l. and all fields were level. The Spanish fields were selected from a previous study where the main dryland cereal production areas of semiarid Aragon with a mean annual rainfall of <400 mm were characterized in terms of their susceptibility to wind erosion (López et al., 2001). The selected fields were representative of the different situations of the wind erodibility of the soils of each region, based mostly on their different textural composition. Soils of the Semiarid Pampas were classified as Typic Ustipsamments and Entic Haplustolls and those of Central Aragon as Calcixerolic Xerochrepts, Petrocalcic Xerochrepts and Lithic Xerorthents (Soil Survey Staff, 1975).

Two soils submitted to two contrasting management conditions were sampled in each field of Argentina: a virgin soil under *Calden* forest (*Prosopis caldenia,* Burk.), an ecosystem submitted to extensive grazing and never ploughed, and an adjacent agricultural soil, under continuous cropping since more than 50 years after *Calden* deforestation. This

Table 1
Main characteristics of the studied soils in the 0–2.5 cm depth

Country	Site	Management	Sand 2000–50 μm (g kg^{-1})	Silt 50–2 μm (g kg^{-1})	Clay<2 μm (g kg^{-1})	Organic matter (g kg^{-1})	$CaCO_3$ (g kg^{-1})
Argentina	1	Cultivated	257	495	248	27.5	0.0
		Calden	278	529	193	34.2	0.1
	2	Cultivated	755	138	106	12.5	0.6
		Calden	714	150	135	33.8	0.0
	3	Cultivated	801	107	92	14.6	0.0
		Natural grass	779	120	101	20.7	0.0
		Cultivated	825	88	88	10.8	0.4
		Natural grass	803	98	99	13.4	0.3
	4	Cultivated	576	243	181	20.9	0.7
		Calden	557	280	163	37.4	0.4
		Cultivated	638	222	140	17.0	0.7
	5	Cultivated	112	586	302	22.7	0.5
		Calden	91	603	307	62.1	0.0
	6	Cultivated	226	347	427	28.3	0.0
		Calden	196	584	220	62.2	2.6
	7	Cultivated	558	270	173	14.6	0.1
		Calden	576	288	136	34.7	0.0
	8	Cultivated	245	527	228	26.1	0.0
		Calden	335	470	195	38.7	1.0
	9	Cultivated	357	439	204	22.3	0.1
		Calden	171	498	331	78.6	0.0
	10	*Calden*	598	266	136	42.2	1.5
Spain	11	Cultivated (CT)	264	471	265	12.8	407
		Cultivated (RT)	286	458	256	15.4	387
		Cultivated (NT)	265	481	254	18.7	384
	12	Cultivated (CT)	539	281	179	17.8	199
	13	Cultivated (CT)	416	404	180	10.8	333

CT, conventional tillage; RT, reduced tillage; NT, no tillage. Values are means of three replicates.

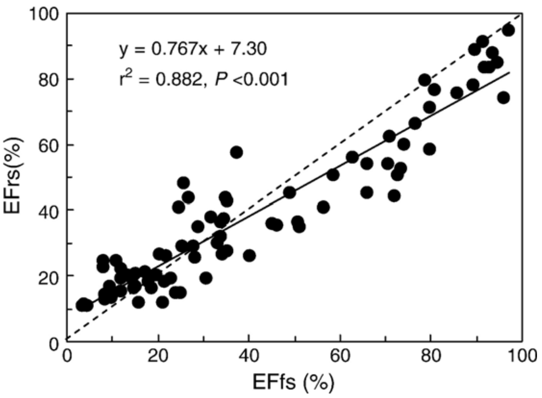


Fig. 1. Relationship between the wind-erodible fraction of the soil surface (0–2.5 cm depth) determined with the rotary sieve (EFrs) and the flat sieve (EFfs).

sampling design allowed the comparison of the prevailing soil use situations of the region: extensive grazing and continuous agriculture. In Spain, all fields were cultivated following the traditional cereal–fallow rotation (one crop in 2 years) of Central Aragon. In this case the following tillage systems were considered: conventional tillage (mouldboard ploughing), reduced tillage (chiselling) and no-tillage.

Soil sampling was carried out between February and March 2004 in both regions, corresponding to the fallow period following primary tillage operations. In all cases three undisturbed soil samples per field were collected from the upper 2.5 cm of the soil with a shovel. After air drying, a portion of approximately 200 g of undisturbed soil samples was separated, crushed with a mortar and sieved through 2 mm to determine the following soil properties: particle size distribution with the pipette method (Gee and Bauder, 1986) for the Argentinian soils, and with laser diffraction (Coulter LS230 laser grainsizer) for the Spanish soils; organic matter and $CaCO_3$ contents were determined with the standard methods (Page et al., 1982) in all samples. Soil surface properties for the selected fields are shown in Table 1.

Two sieving techniques were used to determine aggregate size distribution in all undisturbed soil samples: the standard dry sieving with the rotary sieve (Chepil, 1962) and the dry flat sieving with an electromagnetic sieve shaker (FRITSCH *Analysette 3* PRO). A nest of sieves with 20, 6, 2, 0.84 and 0.42 mm openings was used in both cases. In the flat sieve, an electromagnet transmits vertical vibrations to the sieves. In order to determine with this technique the optimum combination of sieving time and amplitude (vertical vibration height), a series of experiments testing different sieving times and amplitudes were carried out using soils with contrasting EF values. After observing a good separation of soil aggregates, without clogging and breakdown, a sieving time of 5 min and an amplitude of 0.1 mm were finally fixed for 100–200 g undisturbed soil mass. In the rotary sieve, 1–2 kg heavy undisturbed soil sample was used. Sieving through a 0.84 mm sieve was finished as soon as no aggregates remained in the sieve. In both cases, large clods were gently hand broken before added to the sieve.

The EF was calculated as the percentage of dry aggregates <0.84 mm in diameter in relation to the whole soil in both determination systems.

EF was also calculated with the equation proposed by Fryrear et al. (1994):

$$EF = (29.09 + 0.31\,\text{sand} + 0.17\,\text{silt} + 0.33\,\text{sand/clay} \\ -2.59\,\text{organic matter} - 0.95CaCO_3)/100 \quad R^2 = 0.67$$

All these variables are expressed in %.

2. Results and discussion

The amount of the wind-erodible fraction determined with the rotary sieve (EFrs) varied between 11 and 88% and with the flat sieve (EFfs) between 4 and 95%. Following the erodibility classification of Shiyatyi (1965), as cited by Zachar (1982), 32% of the studied soils were highly erodible with EF values >50%, 7% moderately erodible (EF between 40–50%) and 61% slightly erodible (EF<40%). From the highly erodible group, half of these soils presented EF>70%, corresponding in all cases to agricultural soils. Exceptions to this general trend were the slightly erodible *Calden* soils of the Semiarid Pampas, with EF values lower than 40%. In this group were included, likewise, the Spanish soils managed with conservation tillage (reduced tillage and no-tillage).

3.1. Comparison of rotary and flat sieve techniques

Fig. 1 shows the strong relationship ($r = 0.939$; $P < 0.001$) found between EF values obtained with both sieving methods. This result indicates that the flat sieving method adequately measures EF and it can be used as an alternative technique to the standard rotary sieve. Nevertheless, a moderate deviation from the 1:1 line was observed for soils with EF values higher than 40–50%. It could be attributed to an underestimation of the finest fractions of aggregates produced by the rotary sieve. In fact, some amount of the finest aggregates did not pass through the corresponding sieves and was collected along with coarser

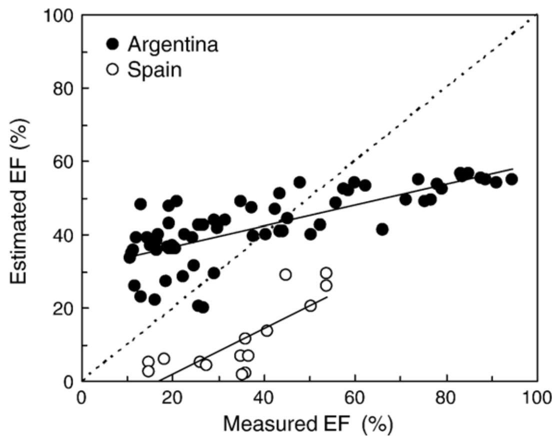


Fig. 2. Relationship between measured (rotary sieve) and predicted wind-erodible fraction (EF) of the soil surface (0–2.5 cm depth) using Eq. (1) for Argentinian and Spanish soils.

Table 2
Correlation coefficients of physical and chemical soil surface properties (0–2.5 cm depth)

	EFrs	EFfs	Sand	Silt	Clay	Org. matter	$CaCO_3$
EFrs [a]	1						
EFfs [b]	0.939 **	1					
Sand (2000–50 μm)	0.841 **	0.782 **	1				
Silt (50–2 μm)	−0.792 **	−0.742 **	−0.960 **	1			
Clay (<2 μm)	−0.732 **	−0.669 **	−0.837 **	0.649 **	1		
Organic matter	−0.384 **	−0.386 **	−0.454 **	0.461 **	0.330 **	1	
$CaCO_3$	−0.122	0.034	−0.245 *	0.243 *	0.190	−0.324 *	1

[a] Wind-erodible fraction obtained with the rotary sieve.
[b] Wind-erodible fraction obtained with the flat sieve.
* Significant at $P<0.05$.
** Significant at $P<0.01$.

aggregates. This effect was stronger in soil samples with larger amounts of fine aggregates. We estimated that EF could be underestimated in this way by about 7–10%. In spite of this and taking into account the different method of aggregate separation and amount of soil sample used in each method, the relationship found between the EF values obtained with both methods is considered acceptable.

The correlation between EFfs and EFrs was better for agriculture ($r=0.972$, $P<0.001$) than for the less disturbed soils (*Calden* in Argentina and no-till in Spanish soils, $r=0.880$, $P<0.05$). This was attributed to the more homogeneous aggregate composition of agriculture soils, as a consequence of tillage, which tends to create a uniform aggregate size distribution. Buschiazzo et al. (2004) showed that the spatial variability of organic matter, an important factor in aggregation formation, was lower in agriculture than in *Calden* soils, as a consequence of tillage homogenization.

The repeatability of both sieving techniques, calculated on the basis of EF variability among the three replicates of each sample, proved that both methods behaved relatively well. The mean coefficient of variation (CV) was 16% for the rotary sieve and 20% for the flat sieve. The range of CV was 1.4–49% with the rotary sieve and 1.4–55% with the flat sieve, with more than half of the cases below 15%. The CV values calculated from data given by Fryrear et al. (1994) for US soils varied from 8.3 to 65% but more than half of the CV was higher than 30% and only a 9% lower than 15%. The CV found in our study indicates that the sampling and sieving procedures used were reproducible and reliable.

3.2. Validation of Eq. (1) for EF calculation in the studied soils

The relationship between measured and predicted EF with Eq. (1) (Fryrear et al., 1994) is shown in Fig. 2. It can be seen that this equation was not successful in predicting EF for Spanish or Argentinian soils. The lack of adjustment between the measured and predicted EF values for Spanish soils can be attributed to their high $CaCO_3$ content (30–40%) which was above the maximum value with which the Eq. (1) was established (25%). Likewise, in the case of Argentinian soils, 32% had a sand/clay ratio lower than the lower limit of the variation range established for using Eq (1) (1.2%). In some cases, the organic matter content was also higher than the upper value of the equation range (4.79%). In addition, whereas the agricultural fields from Argentina and Spain were non-irrigated, there were also irrigated fields in the USA study. In the case of Argentina, native, undisturbed soils of the *Calden* ecosystem, were also considered.

3.3. Development of prediction equations for EF in the studied soils

In order to develop specific prediction equations for our study conditions, correlation analysis among EF and different soil properties were carried out (Table 2). Results show that all soil properties, except $CaCO_3$ content, were correlated significantly with EF. The strongest relations were found with textural fractions, positive with sand content and negative with silt and clay contents. Fig. 3 shows that EF is adequately predicted by the quotient sand/clay and that EF increases with higher sand and lower clay contents, corresponding the highest EF values (95%) to loamy sand soils and the lowest to clay soils (11%). Although weaker than the relationship of EF with texture, significant negative correlation was also observed between EF and soil organic matter content (Table 2). This negative relation agrees with the general association of soil

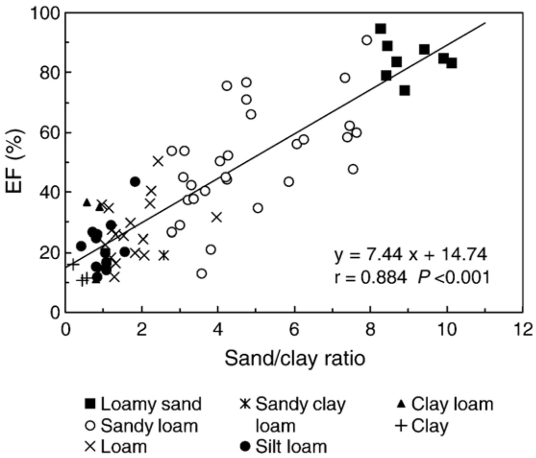


Fig. 3. Relationship between wind-erodible fraction (EF) of the soil surface (0–2.5 cm depth) and sand/clay ratio.

aggregation with high levels of soil organic matter (Kay and Munkholm, 2004).

A multiple regression analysis confirmed that the quotient sand/clay and soil organic matter content were the main properties affecting soil aggregation in the studied soils, explaining 80 to 90% of EF variability. The equations that better predicted EF were:

$$\mathrm{EFrs} = 9.98 + 6.91\ \mathrm{sand/clay} + 14.1/\mathrm{organic\ matter} \quad r = 0.933; P{<}0.001 \tag{2}$$

$$\mathrm{EFfs} = 4.77 + 7.43\ \mathrm{sand/clay} + 27.6/\mathrm{organic\ matter} \quad r = 0.881; P{<}0.001. \tag{3}$$

These significant relationships were considered satisfactory considering the great variety of the soils studied.

4. Conclusions

The comparison of two dry sieve techniques, flat sieving vs. standard rotary sieving, showed that the EF values obtained with the flat sieve were valid and comparable with those obtained using the rotary sieve. Thus, flat sieving can be considered as a suitable alternative to the standard method for EF determinations. The estimation equation of EF proposed by Fryrear et al. (1994) was not useful for predicting EF for Argentinian and Spanish soils. The sand/clay ratio and organic matter were the best predictive variables of EF (r=0.933; P<0.001) in these soils.

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